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The Next Generation Earth Observation System

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NPOESS:

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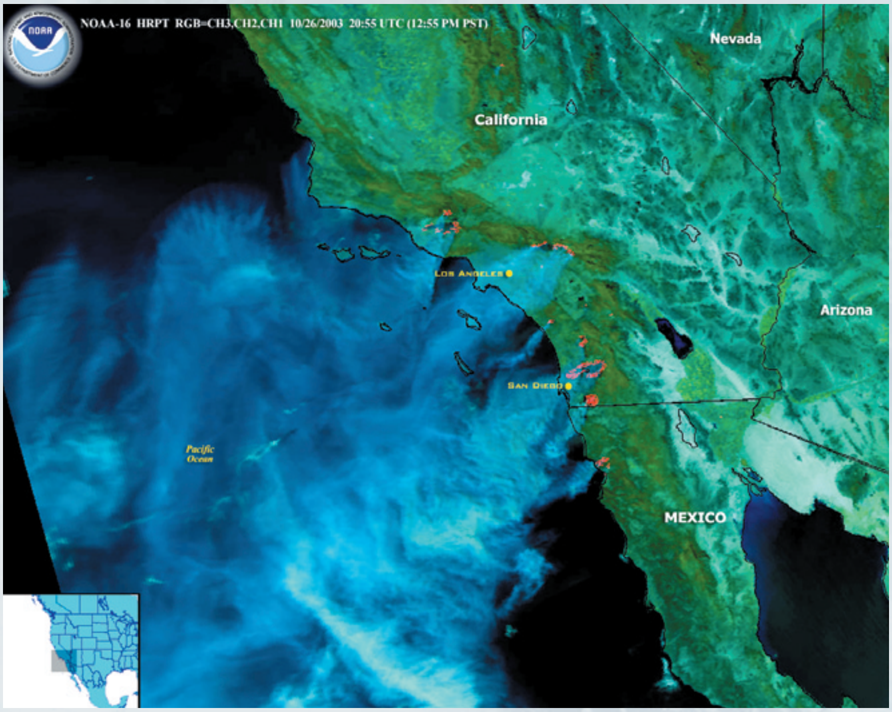
This is the second in a series of articles on the National Polar-orbiting Operational Environmental Satellite System (NPOESS). Last month's article provided an overview of the operations, applications, and benefits of polar-orbiting and geostationary environmental satellites. This month we review the NPOESS program from early convergence of civil and military polar-orbiting satellite programs through system development to pre-operational testing that will highlight the transition from NASA's research and development systems to NOAA's operational measurements.



NOAA-15 POES image of California Fires: *The image depicts the California fires as seen by the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-15 POES. This image was taken on October 26, 2003 at 20:55 UTC (12:55 PM PST). The maximum resolution at nadir is 1 km.*

Introduction

The United States currently maintains two separate, but complementary, Polar-orbiting operational "weather" satellite systems, each with more than 40 years of successful service. As discussed in last month's article, the Department of Commerce's (DOC) National Oceanic and Atmospheric Administration (NOAA) is responsible for the Polar-orbiting Operational Environmental Satellite (POES) program and the Department of Defense (DoD) is responsible for the Defense Meteorological Satellite Program (DMSP). Both satellite programs collect, process, and distribute remotely-sensed, global atmospheric, oceanic, terrestrial, and space environmental data to support short-term weather warnings and forecasts, monitoring of natural hazards, climate research, global military operations, and emergency search and rescue efforts. The POES and DMSP spacecraft have revolutionized the way in which we observe and predict the weather. The next generation environmental satellite systems will evolve and expand our capabilities to observe, assess, and predict the total Earth system—atmosphere, ocean, land, space environment, and climate.

Converging Civil and Military Weather Satellites

Government officials recognized some 25 years ago that a common operational weather satellite system could reduce duplication of efforts between DoD and NOAA and reduce overall costs to the taxpayer. Eight previous attempts to combine DMSP and POES failed, in part, because of strong perceptions within DoD and NOAA of the unique and different military and civil requirements for remotely-sensed data. Although the missions of the military and civilian agencies supported by POES and DMSP are different and have changed over the years, similar types of environmental observations are required to support both missions. As recently as the late 1980s, both DoD and NOAA were developing plans to improve, build, and operate the next series of separate DMSP and POES spacecraft.

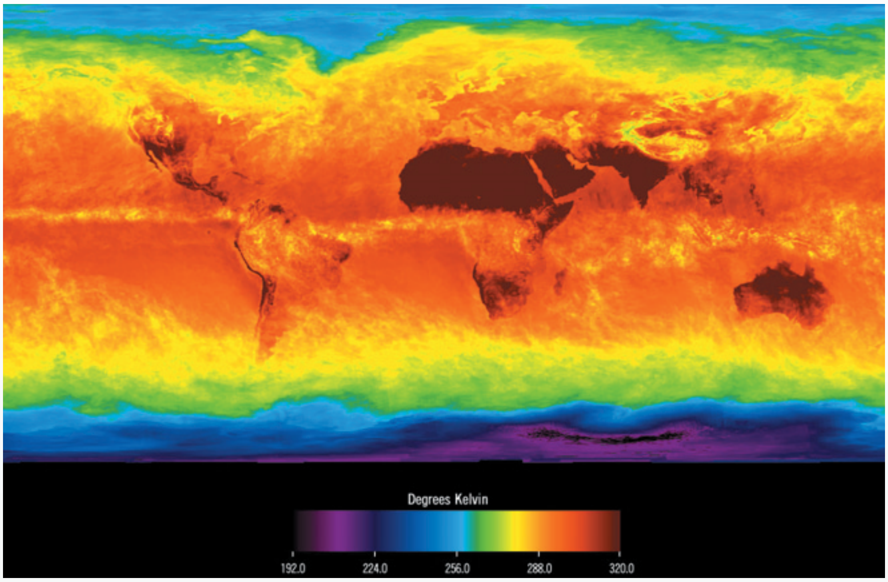
The Next Generation Earth Observation System

Changes in world politics with the end of the "Cold War" and declining agency budgets, however, prompted a re-examination of combining the two systems and in 1992, a National Space Council study recommended convergence of the two separate weather satellite systems. In February 1993, Congress requested that DoD and DOC determine how to converge the DMSP and POES programs and investigate the use of advanced technologies from the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) program. Following further recommendations contained in the 1993 National Performance Review, a tri-agency (DoD, DOC, and NASA) study concluded that a converged system could reduce agency duplication and bureaucracy, substantially reduce costs, and satisfy both civil and military requirements for operational, space-based, remotely sensed environmental data. A Presidential Decision Directive (PDD) was signed on May 5, 1994 directing DoD and DOC to converge their independent Polar-orbiting operational environmental satellite systems into a single, integrated system. The joint system, the National Polar-orbiting Operational Environmental Satellite System (NPOESS), is expected to satisfy both civil and military requirements for space-based, remotely sensed environmental data and once operational, later this decade, it will replace the current POES and DMSP systems.

NPOESS is being specifically designed to provide a single, national Polar-orbiting operational remote sensing system, achieve measurable cost savings, incorporate new remote sensing technologies from NASA, and encourage International cooperation, including the open distribution of environmental data. Compared to the costs of the previously planned upgrades to the separate POES and DMSP satellite systems, the NPOESS program is currently expected to save more than a billion dollars through ~2018.

In October 1994, an Integrated Program Office (IPO) was created by DOC, DoD, and NASA in Silver Spring, Maryland to develop, manage, acquire, and operate NPOESS. The Integrated Program Office provides each of the participating agencies with lead responsibility for one of three primary areas. DOC, through NOAA, has overall responsibility for the converged system, is responsible for satellite operations and provides the primary interface for the international and civil user communities. DoD is responsible for supporting the IPO for major systems acquisitions, including launch support. DOC, through NOAA, and DoD, through the U.S. Air Force (USAF), both fund the NPOESS program through their respective annual budgetary processes. NASA is the principal agency responsible for facilitating the

High Resolution Image of Southern California Fires from MODIS: *This image is from the MODIS sensor on board NASA's Terra satellite taken on October 26, 2003 at 18:40 UTC (10:40 AM PST). MODIS is the precursor to the VIIRS sensor on NPOESS. Notice the increased resolution (up to 250 m) from the NOAA AVHRR satellite. VIIRS will deliver much more information to decision makers at much higher resolutions. Image courtesy of MODIS Rapid Response Team, NASA Goddard Space Flight Center. Image enhanced by StormCenter Communications.*



AIRS Global Average Brightness Temperature for April 2003: *This AIRS image shows average global temperatures in April 2003. With more than 2,000 channels sensing different regions of the atmosphere, the system creates a global, 3-D map of atmospheric temperature and humidity and provides information on clouds, greenhouse gases, and many other atmospheric phenomena. AIRS is the predecessor to the Cross-track Infrared Sounder (CrIS) which will provide improved measurements of the temperature and moisture profiles in the atmosphere. CrIS will fly on board NPOESS. Image courtesy of JPL.*

development and incorporation of new cost-effective remote sensing technologies (*e.g.*, instruments, data assimilation techniques, and scientific understanding) into the converged system. Tri-agency work teams staff each division within the IPO to maintain the integrated "team" approach. "By working together on this advanced satellite system, the three agencies will make the nation's environmental satellite system more efficient, cost effective and more responsive to our country's environmental information needs," according to retired Navy Vice Adm. Conrad C. Lautenbacher, Ph.D., Undersecretary of Commerce for Oceans and Atmosphere and NOAA Administrator. "This new system will provide vital information about our weather, environment, climate, and oceans. In addition, our integrated effort is expected to result in taxpayers saving an estimated [$1.3] billion over the NPOESS lifetime."

An early step in convergence was the transfer in May 1998 of Satellite Control Authority for the existing DMSP satellites from the USAF Space Command to the NPOESS IPO. The command, control, and communications functions for the DMSP satellites were combined with the control for NOAA's POES satellites at NOAA's Satellite Operations Control Center (SOCC) in Suitland, Maryland. A second DMSP satellite operations center, manned by USAF Reserve personnel, was established at Schriever Air Force Base, Colorado to provide redundancy in case the Suitland SOCC encountered any problems. According to Col. James T. Mannen, USAF (Ret.), former director of the IPO, "This installation represents a major milestone in the planned merger of two environmental satellite programs operated by the federal government—the Defense Department's and the National Oceanic and Atmospheric Administration's."

The transfer of DMSP operations was accomplished on budget in less than four years and allowed the USAF to close two DMSP satellite operations control facilities three months ahead of schedule and realize considerable long-term cost savings.

Users Define the Next Generation System

The definition of the environmental requirements for NPOESS was critical to the convergence process. As the operational weather forecasting and climate science communities advance, so too do their needs for space-based observations of the Earth system. To meet these requirements, NPOESS is being designed to observe significantly more phenomena at higher spatial (horizontal and vertical) and temporal resolution simultaneously from space than its POES and DMSP predecessors. Knowing this, the tri-agency partners agreed upon a set of 55 atmospheric, oceanic, terrestrial, climatic, and solar-geophysical measurements (*e.g.*, atmospheric temperature and moisture profiles, precipitable water, vegetation index, sea surface temperature, ocean surface winds, aerosols, ozone, ionospheric scintillation, etc.) that span the Earth science disciplines. These measurements, as well as performance criteria for each measurement, are called Environmental Data Records (EDRs). The development of advanced technology visible, infrared, and microwave imagers and sounders for NPOESS is being guided by EDR needs and is expected to provide enhanced capabilities to users and improve the accuracy and timeliness of observations.

There are six high priority EDRs that are "key" to the NPOESS program: (1) atmospheric vertical moisture profile; (2) atmospheric vertical temperature profile; (3) cloud and ice imagery; (4) sea surface temperature; (5) sea surface winds (speed and direction); and (6) soil moisture. Performance criteria (*e.g.*, horizontal/vertical resolution, measurement precision/uncertainty, refresh rate, data latency) for each of the 55 EDRs were defined with "threshold" values that represent minimally acceptable performance and "objective" levels that represent performance that would have significant added value to users. During the instrument design phase, competing contractors traded cost and performance for sensors and algorithms between "threshold" and "objective" levels to design the "best value" instruments while staying within the expected budget for NPOESS. The best value was defined as obtaining the best performance at an affordable cost.

The planned evolution from the current POES and DMSP programs to NPOESS will take place over the next six to ten years. Currently the U.S. is operating two primary POES and two primary DMSP satellites. Additional POES and

DMSP spacecraft are already built and waiting to be launched when the current satellites in orbit fail. The initial replacement strategy for the transition from POES and DMSP to NPOESS required a new contract to deliver the first NPOESS spacecraft in time to backup the last launch of POES in March 2008. However, the delays in the NPOESS development program that have resulted from budget reductions imposed on the program over the past two years now mean that the first launch of an NPOESS spacecraft will not occur until November 2009 at the earliest.

Although not directly related to NPOESS, in September 2003, the last NOAA POES satellite, NOAA-N′ (N-prime), was involved in a mishap while being assembled at the factory. An investigation team has been created to determine the extent of the damage to the satellite and to recommend actions to be taken to minimize the risk of gaps in environmental data from our Polar-orbiting satellites.

Government/Contractor Team Develops System

One of the most difficult and time-consuming aspects of a new satellite program is the development of sensors and the algorithms needed to transform raw electromagnetic measurements into useful geophysical data products for users. In 1997, the IPO awarded multiple contracts to industry to ensure early development of the critical sensor suites and the algorithms necessary to support NPOESS. Sensor development was started early consistent with the historical timelines for complex environmental instruments. For example, development of the Moderate Resolution Imaging Spectroradiometer (MODIS) and Atmospheric Infrared Sounder (AIRS) on NASA's Aqua satellite took more than seven years to complete. In August 2001, preliminary design efforts were completed for the last of five critical imaging/sounding instruments for NPOESS. Final design, prototype development, and fabrication of these instruments have begun. The first flight units for four sensors are scheduled for delivery in 2005 for the NPOESS Preparatory Project.

Early Flight Testing — a Path from Research to Operations

Previous experience in developing and operating complex environmental satellites has shown that rigorous pre-flight testing is essential to ensure success. End-users must also be prepared in advance to accept, use, and benefit from the full economic and scientific value of the data streams from new systems. The NPOESS program includes the following aircraft and on-orbit tests of prototype instruments and systems. These projects will demonstrate and validate the new imaging and sounding instruments, algorithms, and ground data processing and distribution systems prior to the first NPOESS launch in late 2009.

The NPOESS Airborne Sounder Testbed (NAST) consists of infrared and microwave sounders flying on the NASA ER-2 and Proteus research aircraft. NAST is being used to: test and validate the measurement technologies for the CrIS and ATMS instruments on NPOESS; evaluate algorithms that will be used to derive atmospheric temperature and moisture profiles from CrIS and ATMS; and provide "ground-based" measurements for calibration and validation efforts. NAST is also being used to test the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS), an instrument technology similar to CrIS, that is currently being evaluated for use on NOAA's next generation of Geostationary Operational Environmental Satellites.

The DoD/IPO Coriolis/WindSat mission was launched in January 2003 to provide a space-based test and demonstration of passive microwave polarimetric techniques to derive measurements of ocean surface wind direction, in addition to the surface wind speed previously available from the Special Sensor Microwave Imager (SSM/I) on DMSP. The first twelve months of on-orbit operations of WindSat have demonstrated improved spatial resolution over the SSM/I and successful passive measurement of both wind direction and wind speed. This planned three-year mission continues the development of improved microwave measurement capabilities that leads to CMIS on NPOESS. CMIS will be flown in all three NPOESS orbits to provide higher spatial and temporal resolution mapping of the ocean surface wind field.

NOAA, in cooperation with the IPO and the U.S. Navy, is upgrading and enhancing processing and distribution capabilities to begin acquiring and using near real-time data from MODIS and AIRS on NASA's Terra and Aqua spacecraft to directly support operations. Because MODIS and AIRS are similar to VIIRS and CrIS that will be flown on NPOESS, these early efforts are critical to reduce risk and gain experience with advanced technology instruments and the data handling, processing, storage, and communication of these high volume data sets. End-users will gain early, pre-operational experience with NPOESS-like data sets, well before the first operational NPOESS spacecraft is launched.

The NPOESS Preparatory Project (NPP), a joint IPO/NASA mission, is planned for launch in October 2006. NPP will carry four NPOESS sensors (VIIRS, CrIS, OMPS, and the NASA-developed ATMS) to provide on-orbit testing and validation of sensors, algorithms, and ground-based operations and data processing systems. Because the current operational POES and DMSP and the NASA Earth Observing System (EOS) research satellite systems will still be in place, operational forecasters and research scientists will be able to compare and validate new measurements from NPP with observations from the heritage systems. NOAA, DoD, NASA, and other end-users will have early access to the next generation of operational sensors, thereby greatly reducing the risks incurred during the transition from POES and DMSP to NPOESS. NPP should also provide continuity of the calibrated, validated, and geo-located NASA EOS Terra and Aqua global imaging and sounding observations for NASA Earth Science research. With a five-year design lifetime, NPP will provide a "bridge" from NASA's EOS research missions (Terra, Aqua, and Aura) to the operational NPOESS mission.

While sensors are the "business" end of the system, other critical components are needed to transform "raw" data collected in space into data products that can be delivered easily to end users on the ground. The "end-to-end" system includes: sensors; spacecraft; command, control, communications, data routing; and ground processing. In August 2002, the IPO awarded a single prime contract to Northrop Grumman Space Technology (NGST) to accomplish the Acquisition and Operations phase of NPOESS. NGST, with its principal teammate Raytheon and primary instrument subcontractors (ITT Industries, Ball Aerospace and Technologies Corp., Boeing Space Systems, and Saab Ericsson Space), will develop, fabricate, and deliver the NPOESS satellite and ground systems as well as provide launch support, operations, and support services for the system. "This [government/contractor team] effort ultimately means the war fighter is receiving higher quality data sooner, and we're doing it with very significant cost savings," said Peter B. Teets, Undersecretary of the Air Force. "This is an example of getting our acquisition programs back on track and saving valuable defense dollars wherever we can."

Thirteen different instrument payloads will be flown on NPOESS spacecraft in three different configurations, depending upon orbit. NPOESS payloads include instruments to:

❶ *Profile the Atmosphere* (Cross-track Infrared Sounder [CrIS], Advanced Technology Microwave Sounder [ATMS], Ozone Mapping and Profiler Suite [OMPS], and Aerosol Polarimetry Sensor [APS]);

❷ *Probe the Space Environment* (Global Positioning System Occultation Sensor [GPSOS] and Space Environment Sensor Suite [SESS]);

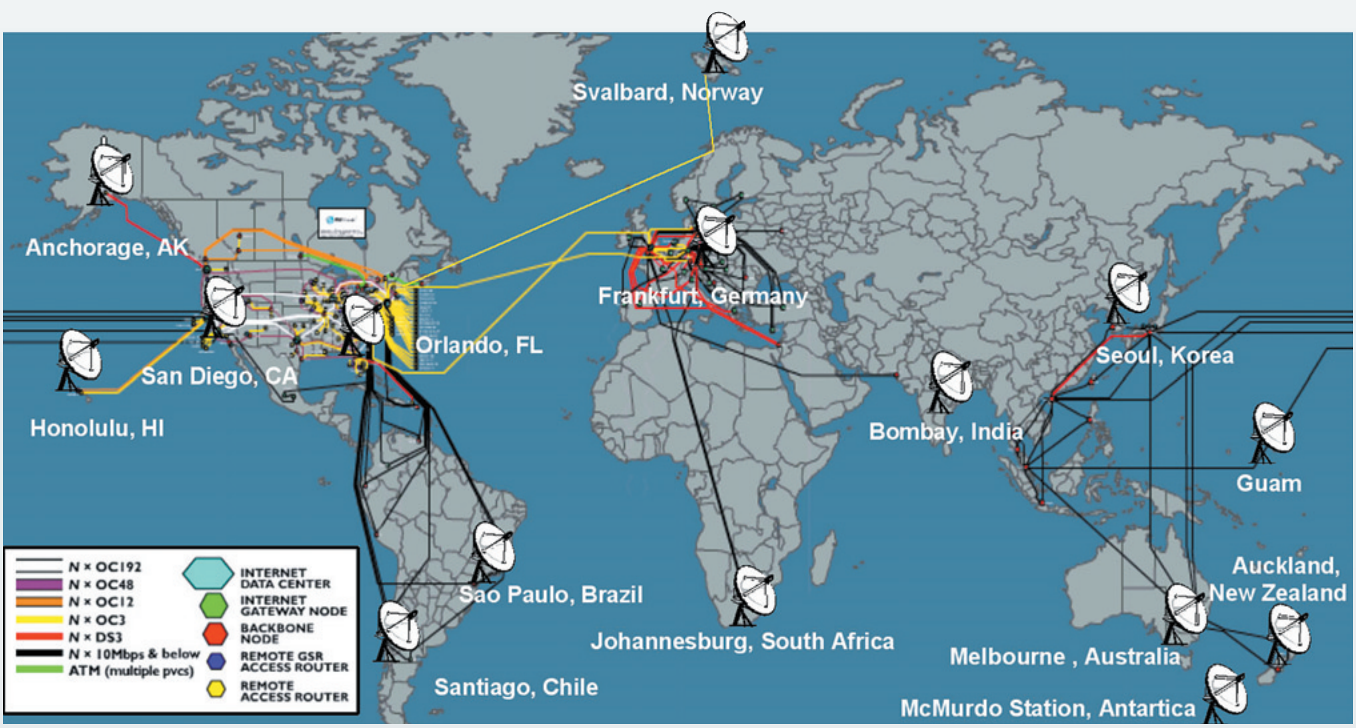
❸ *Monitor the Earth's Radiation Budget* (Total Solar Irradiance Sensor [TSIS] and Earth Radiation Budget Sensor [ERBS]);

❹ *Map the Ocean Surface* (radar altimeter [ALT]); and

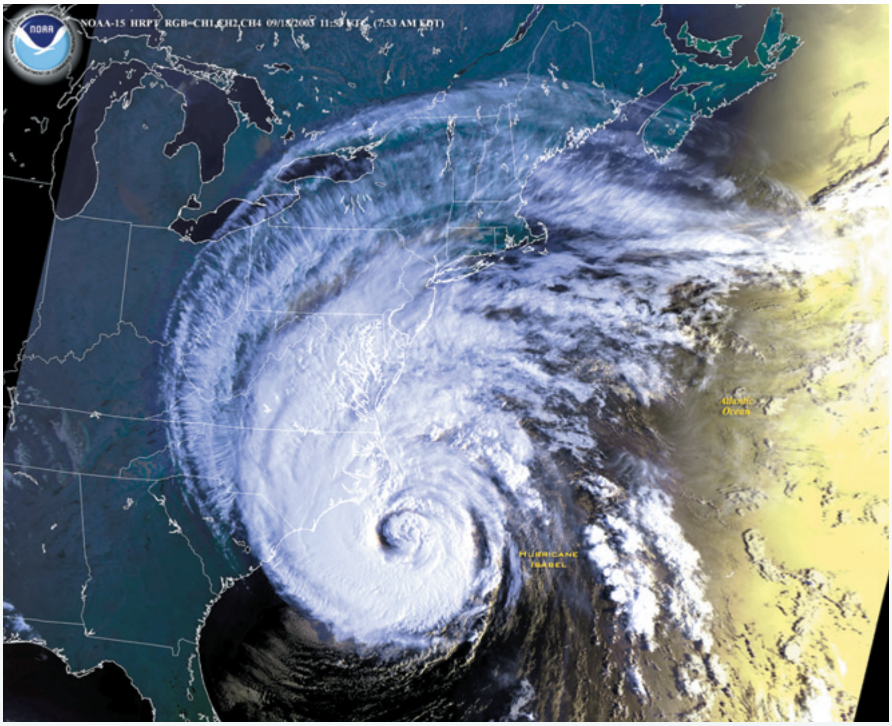
❺ *Observe other Atmospheric, Terrestrial, and Oceanic* phenomena globally (Visible/Infrared Imager Radiometer Suite [VIIRS] and Conical-scanning Microwave Imager/Sounder [CMIS]).

Data from multiple instruments will be used to produce specific products. For example, near-simultaneous infrared (from VIIRS) and microwave (from CMIS) measurements of sea surface temperature (SST) will be combined to derive "all weather" global and regional SST products. NPOESS will continue the current capabilities on POES for search and rescue (Search and Rescue Satellite Aided Tracking System [SARSAT]) and surface data collection/location (Advanced/Data Collection System [A-DCS], also known as ARGOS) that are important to a broad user community for relaying data from fixed and mobile, oceanic and terrestrial environmental observation platforms. The instruments and spacecraft components for NPOESS are being designed to ensure a mission life exceeding five years for each of the six NPOESS spacecraft that will be flown over the life of the program (2009-2019). This is a significant improvement over the average on-orbit life of POES or DMSP spacecraft (36-48 months) and comparable to what NASA is currently achieving in its EOS missions.

When NPOESS is fully operational in 2013, there will be three spacecraft flying at an altitude of 828 km in sun-synchronous orbits. Polar-orbiting satellites in sun-synchronous orbits pass over the same part of the Earth at roughly the same local time each day. NPOESS



SafetyNet: *NPOESS will use a globally distributed network of 15 unmanned, low-cost ground receptors. The data received by these receptors passes through existing commercial fiber optic networks to the four U.S.-based environmental processing centrals. These are the main data processing centers for weather data. SafetyNet is a patent pending technology of Northrop Grumman Space Technology.*



NOAA POES Image of Hurricane Isabel: *This NOAA-15 POES image of Hurricane Isabel captures the entire storm in one swath. The Advanced Very High Resolution Radiometer (AVHRR) sensor will be replaced with more advanced technology on NPOESS to capture weather systems at much higher resolution. The bright strip to the right of the storm is the sun reflecting off the Atlantic ocean otherwise known as "sun glint." This image, courtesy of NOAA, was taken by NOAA-15 on September 18, 2003 at 11:53 UTC (7:53 AM EDT).*

spacecraft will be launched into orbits so that the three spacecraft cross the Equator at 1330, 1730, and 2130 local solar time, respectively. Equally spaced orbits for NPOESS will provide global coverage with a data refresh rate (local average time interval between consecutive measurements of a parameter at the same location) of approximately four hours for most observations. Ground controllers will be able to perform on-orbit maneuvers of the NPOESS spacecraft to maintain altitude and Equatorial crossing times throughout the mission lifetime. This capability to make measurements at "precisely" the same time each day is important to maintain consistency in the long-term data records (*e.g.,* tropospheric temperatures) required for climate change analysis and assessment and will provide exceptional coverage for ongoing events. Because the requirements for data refresh rates are different for many of the 55 environmental parameters, not all instrument payloads are required in each orbit. Consequently, the afternoon spacecraft will carry the largest complement of instruments. However, the early-morning and mid-morning NPOESS spacecraft will carry fewer instruments, but will carry VIIRS and CMIS that are needed for "all-weather" imaging (visible/infrared and microwave) and ocean surface wind field mapping in these orbits.

Most of the NPOESS sensors are considerably more complex and have data rates that are two orders of magnitude greater than the instruments carried on either DMSP or POES. These higher data rates will require more frequent space-to-ground data relay. The NPOESS communications system will dramatically shorten data latency (time from observation by the satellite to availability of processed data) to satisfy growing user needs for more real-time data to support operations and research. Global data stored onboard the NPOESS spacecraft will be delivered to four U.S. facilities (Centrals) for processing and distribution to users.

NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) serves the National Centers for Environmental Prediction (NCEP) and other NOAA offices, as well as U.S. civilian organizations. The other three Centrals are for the U.S. military: the Air Force Weather Agency (AFWA); Fleet Numerical Meteorology and Oceanography Center (FNMOC); and the Naval Oceanographic Office (NAVOCEANO). Data stored on satellites will be transmitted to 15 globally-distributed, low-cost, unmanned ground stations that will be tied to the four Centrals via commercial fiber-optic networks.

This innovative "SafetyNet*" (patent pending technology) ground system is being developed by the NGST/Raytheon team and will deliver 77% of the global (daily average) data to Centrals within 15 minutes and 95% of the data (daily average) within 28 minutes from the time of on-orbit collection. This is a dramatic improvement over the ~120-180 minute data latency for global stored data from POES and DMSP. In addition to the space-to-ground transmission of stored data, NPOESS will simultaneously broadcast two continuous real-time data streams, at high and low rates, to suitably equipped field terminals worldwide. NOAA's NESDIS will be responsible for providing access to the worldwide user community for near real-time processed NPOESS data and higher-level products. NESDIS will also maintain the long-term archive of NPOESS data.

Next month's article will focus on the NPP "bridge" mission in more detail and its role in the transition from NASA research to NOAA operations.

About the Author

Dave Jones is Founder, President and CEO of StormCenter Communications, Inc. He is also President of the ESIP Federation (*esipfed.org*) and Chairman of the Board for the Foundation for Earth Science. You can reach Dave at *dave@stormcenter.com*.

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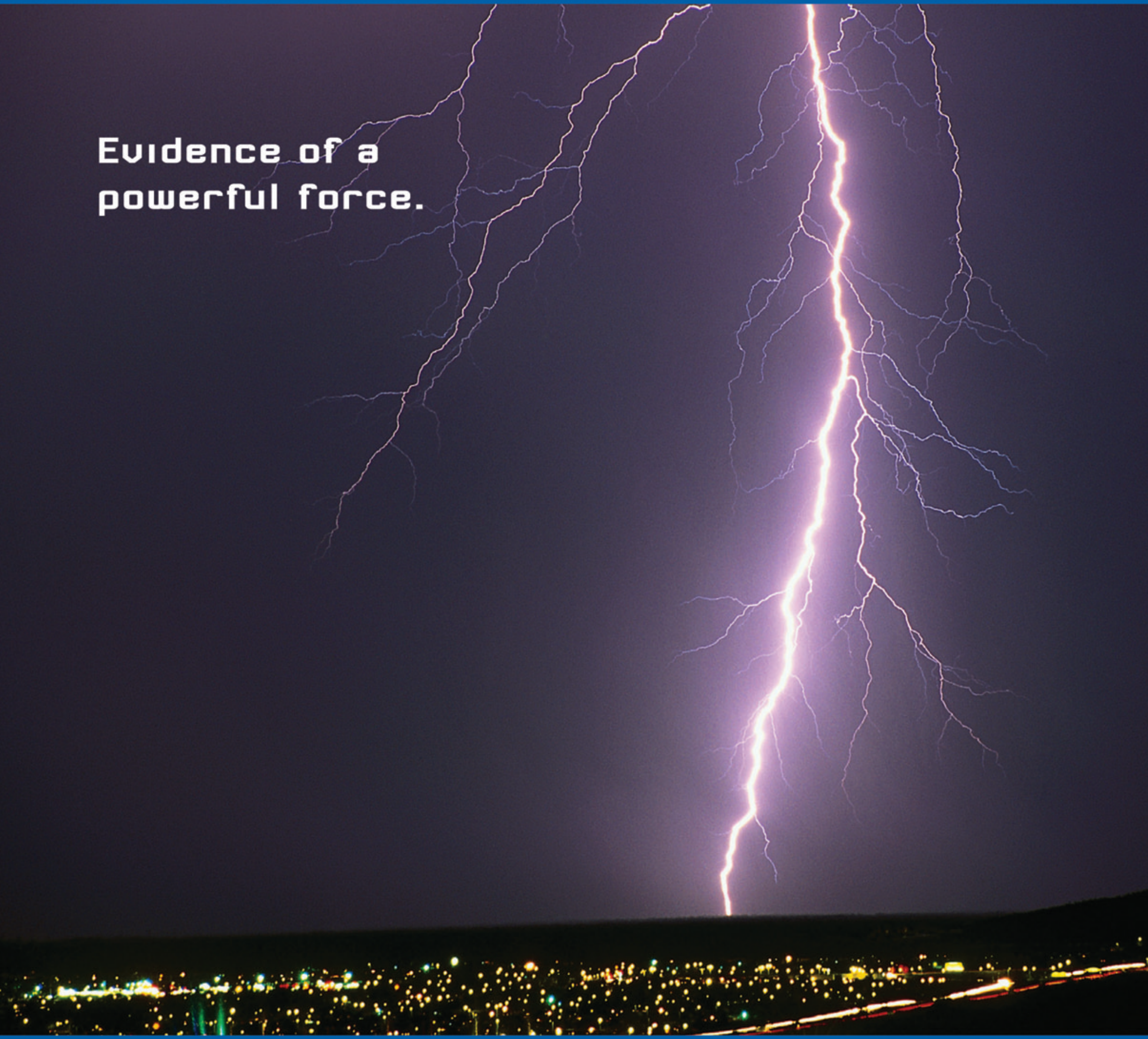

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